SHOCK ISOLATION SYSTEM

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

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BACKGROUND OF THE INVENTION

1) Field of the Invention

The present invention relates to shock isolation and, more particularly, to a system for reducing the transmission of energy in the form of shocks, including vibrations, between devices while maintaining angular orientation of the devices.

2) Description of Related Art

A typical aerospace vehicle in a missile defense system includes a kill vehicle that is releasably connected to a boost device. The boost device provides thrust for launching the kill vehicle and directing the vehicle towards a target, such as a missile in flight. At a predetermined stage of flight, such as upon completion of the combustion of the fuel in the boost device, the kill vehicle and the boost device separate and the kill vehicle continues toward the target. Prior to separation, the boost device can communicate guidance information to the kill vehicle, including current location, orientation, and velocity information for the boost device. The kill vehicle also has a guidance system that controls the flight of the kill vehicle toward the target, based in part on the guidance information received from the boost vehicle.

While the boost device and kill vehicle are connected, the boost device can provide significant thrust to the kill vehicle, and shock motion associated with the thrust can damage equipment in the kill vehicle such as electronics in guidance or other avionic devices. Elastomeric isolators are conventionally used for reducing the transmission of shocks, including vibrations, but the use of isolators for connecting the boost device and kill vehicle can allow undesirable or unacceptable rotational motion therebetween, i.e., about a longitudinal or roll axis that extends through the boost device and kill vehicle. This relative motion between the boost device and kill

vehicle can complicate the determination of the guidance of the kill vehicle because the guidance information determined by the boost vehicle may not directly correspond to that of the kill vehicle. For example, the guidance information communicated by the boost device before separation may not accurately describe the orientation of the kill vehicle if the kill vehicle is rotated about the roll axis relative to the boost device. However, if isolators are not used, the electronic equipment in the kill vehicle must be designed to withstand the shocks associated with the boost device. This generally increases the cost and weight of the electronic equipment.

Thus, there exists a need for an improved system for reducing the transmission of shocks, including vibrations, between devices while maintaining the relative rotational orientation of the devices. Preferably, the system should be compatible with an aerospace vehicle in which a boost device generates significant and/or repetitive shocks.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a shock isolation system for reducing a transmission of energy in the form of shocks between first and second devices, such as a boost device and a kill vehicle of an aerospace vehicle. The system includes at least two linear bearing assemblies that extend parallel in an axial direction between the first and second devices. Each bearing assembly has a shaft member connected to one of the first and second devices and a linear bearing connected to the other of the devices. The linear bearings are configured to adjust, i.e., move, axially on the shafts so that the first and second devices are configured for relative motion therebetween in the axial direction and the bearing assemblies restrain a rotation between the first and second devices about an axis defining the axial direction. The system also includes at least two isolators configured to be axially loaded by a relative motion between the first and second devices in the axial direction. At least one of the isolators is deformed by the relative axial motion to at least partially reduce the transmission of energy between the devices. Further, the centers of gravity of the devices can be positioned outside a plane defined by the isolators, and the linear bearing assemblies can be configured for independent axial adjustment, i.e., movement, so that the first device can rotate relative to the second device about an axis transverse to the axial direction.

According to one aspect of the invention, the linear bearing assemblies and isolators are arranged in a substantially planar and polygonal configuration. Each linear bearing can extend circumferentially around the shaft and can have a plurality of balls for rollably contacting the shaft. The isolators, which can be formed of rubber, elastically deformable polymers, or springs, can be positioned on opposite sides of the linear bearings and also can extend circumferentially around the shafts. Alternatively, each isolator can extend between the first and second devices separately from the bearing assemblies.

Thus, the shock isolation system of the present invention reduces the transmission of energy between the devices while maintaining the rotational orientation therebetween.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

Figure 1 is a perspective view illustrating an isolation system disposed between a boost device and a kill vehicle according to one embodiment of the present invention;

Figure 2 is an elevation view illustrating one of the bearing assemblies with two isolators of the isolation system of Figure 1;

Figure 3 is a section view in elevation illustrating the bearing assembly and isolators of Figure 2;

Figure 4 is an elevation view schematically illustrating an isolation system according to another embodiment of the present invention; and

Figure 5 is a section view as seen along line 5-5 of Figure 4 schematically illustrating the isolation system of Figure 4; and

Figures 6-9 are section views in plan schematically illustrating isolation systems according to other embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

Referring now to the figures and, in particular, to Figure 1, there is shown an aerospace vehicle **10** with an isolation system **20** according to one embodiment of the present invention. The illustrated aerospace vehicle **10** includes a kill vehicle **50** that is connected to a boost device **60**, or boost vehicle. In other embodiments, the isolation system **20** can be used to isolate the transmission of shocks between portions of other aerospace vehicles and structures. Further, the isolation system **20** can be used for other vehicles and structures, such as for isolating navigational or guidance equipment from the structure of an aircraft, ship, or other vessel, for isolating an engine from the chassis of an automobile, for isolating a pump, motor, or other equipment from a building structure, and the like. Thus, the isolation system **20** can be used in a variety of applications.

The aerospace vehicle **10** shown in Figure 1 can be launched from the ground by operation of the boost device **60**. For example, the boost device **60** can include a solid or liquid fuel, which is combusted during a first stage of flight to propel the vehicle **10** into or above the atmosphere. The kill vehicle **50** is connected to the boost device **60** by releasable connections **70** so that the kill vehicle **50** can be released from the boost device **60** and proceeds in a second stage of flight to a target. For example, the releasable connections **70** can include an electrically-, pneumatically-, or hydraulically-actuated clamping system for connecting and releasing the boost device **60** and the kill vehicle **50**. Alternatively, each releasable connection **70** can be a pyrotechnically-charged device that combusts to effect the release. The shock isolation system **20** shown in Figure 1 is disposed between the boost device **60** and the kill vehicle **50** and, in particular, between the releasable connections **70** and boost device **60**. Thus, the isolation system **20** can be released with the boost device **60** from the kill vehicle **50**. In other embodiments of the present invention, however, the isolation system **20** can be disposed between the releasable connections **70** and the kill vehicle **50** so that the isolation system **20** is released from the boost device **60**.

The first stage of flight of the aerospace vehicle **10** can end at a predetermined time, such as when substantially all of the fuel in the boost device **60** has been combusted, after a predetermined duration, or when the vehicle **10** reaches a predetermined altitude, location, or speed. A propulsion system **52** within the kill vehicle **50** can provide propulsion during the second stage of flight to propel or guide the kill vehicle **50** toward the target. The target can be, for example, a missile or other ballistic device, and the kill vehicle **50** can be designed to impact thereon to destroy or alter the course of the target. The boost device **60** can be discarded or retrieved after flight.

The foregoing description is an exemplary flight sequence, though it is understood that the sequence can differ in other embodiments of the present invention. For example, the aerospace vehicle **10** can be launched from an intermediate device such as an aircraft or a space-orbital structure, and/or the kill vehicle **50** can remain connected to the boost device **60** throughout the entire flight of the vehicle **10**.

During the first stage of flight, a guidance system **62** in the boost vehicle **60** determines guidance information such as the location, orientation, and velocity of the vehicle **10**. The guidance information can be used to control the combustion of the fuel in the boost device **60**, the operation of a vane or other flight control device, and other aspects of the propulsion. Prior to the separation of the kill vehicle **50** from the boost device **60**, at least some of the guidance information is communicated from the boost device **60** to the kill vehicle **50**. In particular, the current location, orientation, and velocity of the vehicle **10** can be communicated from the guidance system **62** in the boost device **60** to a guidance system **54** in the kill vehicle **50**. Communication of the guidance information can be achieved, for example, by an electronic transmission through a cable (not shown) connecting the guidance systems **62**, **54**.

The shock isolation system **20** includes a combination of linear bearing assemblies **30** and isolators **40**. In the embodiment illustrated in Figures 2 and 3, each linear bearing assembly **30** includes a shaft member **32** and a linear bearing **34**. The shaft members **32** are connected to c-shaped brackets **64** that are connected to the boost device **60** such that the shaft members **32** extend generally parallel in an axial direction of the vehicle **10**. Each linear bearing **34** is connected to the kill vehicle **50** via an adapter **56** and configured to move axially on the respective shaft member **32**. The linear bearings **34** can be constructed according to a variety of configurations, as

is known in the art. For example, each linear bearing **34** can include a cylindrical raceway **36** or cage for holding a plurality of balls **38** in rolling contact with the shaft member **32** as the linear bearing **34** is moved axially on the shaft member **32**. Thus, the bearing assemblies **30** allow a relative axial motion between the kill vehicle **50** and the boost device **60**, i.e., the kill vehicle **50** and the boost device **60** can move axially toward or away from each other.

The isolators **40** are disposed so that relative motion between the boost device **60** and the kill vehicle **50** results in deformation of the isolators **40**, thus damping the motion therebetween. For example, each isolator **40** can extend circumferentially around the shaft members **32** of the bearing assemblies **30**, and two or more isolators **40** can be disposed on each shaft member **32** opposite the linear bearing **34** as shown in Figures 1-3 so that the isolators **40** damp motion of the bearings **34** on the shaft members **32** and, hence, relative motion between the boost device **60** and the kill vehicle **50**.

The isolators **40** can be formed of elastomeric materials such as rubber or elastomerically deformable polymers. Alternatively, the isolators **40** can be springs, such as coil or Belleville springs configured to reduce the axial motion between the boost device **60** and kill vehicle **50**. Further, in some embodiments, springs and elastomeric isolators can be used in conjunction, for example, with one of the elastomeric isolators configured opposite a linear bearing **34** from a Belleville spring.

The isolators **40** can be disposed between the boost device **60** and the kill vehicle **50** at positions other than on the shaft members **32** of the linear bearing assemblies **30**. Thus, the isolators **40** can extend between the boost device **60** and the kill vehicle **50** and can be positioned separately from the linear bearing assemblies **30**. For example, in the embodiment illustrated in Figures 4 and 5, two linear bearing assemblies **30** and four isolators **40** are disposed between the boost device **60** and the kill vehicle **50** in a generally planar and circular configuration with the linear bearing assemblies **30** at diametrically opposite circumferential positions.

Other alternative configurations for the isolators **40** and linear bearing assemblies **30** according to other embodiments of the present invention are schematically illustrated in Figures 6-9. For example, Figure 6 illustrates a configuration of three circumferentially spaced linear bearing assemblies **30**, the shaft member **32** of each linear bearing assembly **30** having two isolators **40** disposed thereon opposite the linear bearings **34**. Figure 7 illustrates a configuration of two

linear bearing assemblies **30** and fourteen isolators **40**. Figure 8 illustrates a configuration of four linear bearing assemblies **30** and twelve isolators **40**. Figure 9 illustrates a configuration of three linear bearing assemblies **30** and twelve isolators **40**. Similar to the isolators **40** shown in Figures 4 and 5, the isolators **40** of Figures 7-9 are provided separately from the linear bearing assemblies **30**. It is understood that the embodiments illustrated in Figure 6-9 are only examples of the many different configurations that are possible. In other embodiments, the isolators **40** and linear bearing assemblies **30** can be configured in non-circular configurations, e.g., generally in the shape of another polygon such as a square, rectangle, triangle, and the like. In addition, the isolators **40** and/or the linear bearing assemblies **30** can be disposed in asymmetric configurations, e.g., so that an elastic center of the isolation system **20** is not collinear with the axial center of the kill vehicle **50** and the boost device **60**. By "elastic center" it is meant the location at which an axial force urging the boost device **60** and the kill vehicle **50** together results in equal deformation of each of the isolators **40**. For example, if a center of gravity of the kill vehicle **50** and/or the boost device **60** are not located along an axis passing through the geometric centers thereof, the elastic center of the isolation system **20** can be made to correspond to the center of gravity of the kill vehicle **50** and/or the boost device **60**.

In operation, the linear bearing assemblies **30** restrict the relative motion between the kill vehicle **50** and the boost device **60** to motion substantially in the axial direction of the shaft members **32**. Transverse motion, i.e., perpendicular to the axial direction, and rotational motion about the axial direction between the boost device **60** and the kill vehicle **50** are thereby prevented. Thus, the guidance information communicated from the boost device **60** to the kill vehicle **50** will accurately describe the orientation of the kill vehicle **50**.

Further, the isolators **40** damp the transmission energy in the form of shocks between the boost device **60** and kill vehicle **50**, which can otherwise occur, e.g., due to the firing of the boost device **60**. The shocks can be characterized by individual or repeated motions, e.g., vibrations that can be generally random or repetitive in nature. The isolators **40** can attenuate axial motion of the boost device **60** relative to the kill vehicle **50**. Further, the isolators **40** can attenuate a relative rotational motion between the kill vehicle **50** and the boost device **60** about an axis transverse to the axial direction. For example, such a lateral motion results when one or more of the linear bearings **34** move independently, e.g., one or more of the linear bearings **34**

move toward the kill vehicle **50** while one or more of the other linear bearings **34** move toward the boost device **60**. As shown in Figure 4, centers of gravity **58, 66** of the kill vehicle **50** and boost device **60**, respectively, can each be located out of a plane defined by the isolators **40** and the linear bearing assemblies **30** to facilitate the attenuation of such a rotation of the centers of gravity **58, 66** about an axis transverse to the axial direction of the vehicle **10**.

Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.